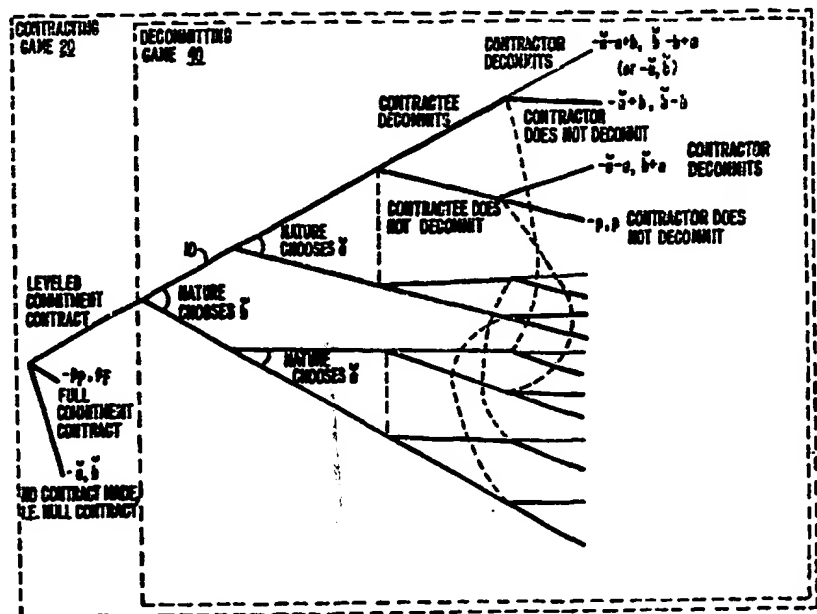




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International Bureau

(51) International Patent Classification <sup>6</sup> : G06F 17/60, 17/10, 9/44		A1	(11) International Publication Number: WO 99/06933 (43) International Publication Date: 11 February 1999 (11.02.99)
(21) International Application Number: PCT/US98/15729 (22) International Filing Date: 29 July 1998 (29.07.98) (30) Priority Data: 08/904,873 1 August 1997 (01.08.97) US (71) Applicant: BUSINESSBOTS, INC. [US/US]; Suite 1450, 301 Howard Street, San Francisco, CA 94105 (US). (72) Inventors: SANDHOLM, Thomas, W.; 6951 Pershing Avenue, University City, MO 63130 (US). LESSER, Victor, R.; 24 Teaberry Lane, Amherst, MA 01002 (US). (74) Agents: WAWRZYNIAK, Richard, E. et al.; McCutchen, Doyle, Brown & Enersen, Three Embarcadero Center, San Francisco, CA 94111 (US).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.	

(54) Title: **LEVELED COMMITMENT CONTRACTING SYSTEM**



**(57) Abstract**

A leveled commitment contracting system involving contracting agents that can decommit based on a predetermined decommitment penalty.

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## Leveled Commitment Contracting System

### Field of the Invention

This invention relates to the field of contracting protocols and, more particularly, to contracting protocols for automated negotiations that can be  
5 implemented in connection with computer networks.

### Background

The importance of automated negotiation systems is likely to increase as a result of three developments. One is the growth of standardized communications infrastructure—EDI, NII, KQML, Telescript etc.—over which separately designed  
10 agents belonging to different organizations can interact in an open environment and safely carry out transactions. The second is the advent of small transaction commerce on the Internet for purchasing goods, information, and communication bandwidth. The third is an industrial trend toward virtual enterprises: dynamic alliances of small enterprises which together can take advantage of economies of scale.

15 In such multiagent systems consisting of self-interested agents, contracts have traditionally been binding. After an agent agrees to a contract, it has to follow through with it no matter how future events unravel. Although a contract may be profitable to an agent when viewed *ex ante*, it need not be profitable when viewed after some future events have occurred, i.e. *ex post*. Similarly, a contract may have too low  
20 expected payoff *ex ante*, but in some realizations of the future events, the same contract may be desirable when viewed *ex post*. Normal full commitment contracts are unable to efficiently take advantage of the possibilities that such—probabilistically known—future events provide.

On the other hand, many multiagent systems consisting of cooperative agents  
25 incorporate some form of decommitment possibility in order to allow the agents to accommodate new events. For example, in the original Contract Net Protocol, the agent that had contracted out a task could send a termination message to cancel the contract even when the contractee had already partially fulfilled the contract. This was possible because the agents were not self-interested: the contractee did not mind  
30 losing part of its effort without a monetary compensation. Similarly, the role of

decommitment among cooperative agents has been studied in meeting scheduling and in cooperative coordination.

Game theory has suggested utilizing the potential provided by probabilistically known future events via *contingency contracts* among self-interested agents. The contract obligations are made contingent on future events. There are games in which this method increases the expected payoff to both parties of the contract compared to any full commitment contract. Also, some deals are enabled by contingency contracts in the sense that there is no full commitment contract that both agents prefer over their fall-back positions, but there is a contingency contract that each agent prefers over its fall-back.

There are at least three problems regarding the use of contingency contracts in automated negotiation among self-interested agents. First, it is often impossible to enumerate all possible relevant future events in advance. Second, contingency contracts get cumbersome as the number of relevant events to monitor increases. In the limit, all domain events (e.g. new tasks arriving or resources breaking down) and all negotiation events (other contracts) can affect the value of the obligations of the original contract, and should therefore be conditioned on. Furthermore, these future events may not only affect the value of the original contract independently: the value may depend *combinations* of the future events. The third problem is that of verifying the unraveling of the events. Sometimes an event is only observable by one of the agents. This agent may have an incentive to lie to the other party of the contract about the event in case the event is associated with an unadvantageous contingency to the directly observing agent. Thus, to be viable, contingency contracts would require an event verification mechanism that is not manipulable and not prohibitively complicated.

Accordingly, there is a need for an improved contracting system that may be implemented in connection with automated negotiations, such as automated negotiations over a computer network.

### Summary of the Invention

The present invention involves a leveled commitment contracting system. In preferred embodiments of such a system, a contractor can decommit upon payment of a decommitment penalty.

### 5                   Brief Description of the Drawings

One or more embodiments of the present invention are described in connection with the following drawings, in which:

FIG. 1 illustrates a "sequential decommitting" ("SEQD") game; the game tree of the figure representing two alternative protocols (i.e., two different games).

10           FIG. 2 illustrates decommitment penalties "a" and "b" that satisfy both agents' IR in an example SEQD game.

FIG. 3 illustrates a "simultaneous decommit - both pay if both decommit game" ("SIMUDBP") game.

15           FIG. 4 illustrates Nash equilibrium decommitment thresholds for an example of an SIMUDBP game for different values of decommitment penalties a and b.

FIG. 5 illustrates three different regions of contracts that are IR for both agents and allow and equilibrium in the SIMUDBP decommitting game.

FIG. 6 illustrates Nash equilibrium decommitment penalties for an example of an SIMUDBP game for different values of decommitment penalties a and b.

### 20                   Detailed Description of Preferred Embodiment(s)

An embodiment of a leveled commitment contracting protocol that allows self-interested agents to efficiently accommodate future events by having the possibility of unilaterally decommitting from a contract based on local reasoning is described below. A decommitment penalty is assigned to both agents in a contract: to  
25   be freed from the contract, an agent only pays this penalty to the other party. It is shown through formal analysis of several contracting settings that this leveled commitment feature in a contracting protocol increases Pareto efficiency of deals and can make contracts individually rational when no full commitment contract can. This advantage holds even if the agents decommit manipulatively.

## 1. Embodiments of Leveled Commitment Contracting System

In preferred embodiments, instead of conditioning the contract on future events, a mechanism is built into the contract that allows unilateral decommitting at any point in time. This is achieved by specifying in the contract decommitment penalties, one for each agent. If an agent wants to decommit—i.e. to be freed from the obligations of the contract—it can do so simply by paying the decommitment penalty to the other party. We will call such contracts *leveled commitment contracts* because the decommitment penalties can be used to choose a level of commitment. The method requires no explicit conditioning on future events: each agent can do its own conditioning dynamically. Therefore no event verification mechanism is required either. This paper presents formal justifications for adding this decommitment feature into a contracting protocol.

Principles for assessing decommitment penalties have been studied in law, but the purpose has been to assess a penalty on the agent that has breached the contract *after the breach has occurred*. Similarly, penalty clauses for partial failure—such as not meeting a deadline—are commonly used in contracts, but the purpose is usually to motivate the agents to follow the contract.

Key microeconomic concepts are now introduced. *Social welfare* is the sum of the payoffs of the agents under consideration. It does not address distribution. *Pareto efficiency* measures both societal good and distribution. A vector of payoffs to the agents Pareto dominates another vector if each agent's payoff in the first vector is no less than in the second, and there exists an agent whose payoff in the first vector is greater than in the second. Social welfare and Pareto efficiency can be measured either *ex ante* as expected values or *ex post* as realizations. Strategies (mappings from observed history of the game to actions)  $S_A$  of the contractor and  $S_B$  of the contractee are in *Nash equilibrium* if  $S_A$  is a best-expected payoff maximizing—response to  $S_A$  and  $S_B$  is a best response. Finally, a strategy is a *dominant strategy* if it is a best response to *any* strategy of the other agent.

To understand the described embodiments, it is useful to analyze contracting situations from the perspective of two agents: the *contractor* who pays to get a task done, and the *contractee* who gets paid for handling the task. Handling a task can

mean taking on any types of constraints. The method is not specific to classical task allocation. The contractor tries to minimize the contract price  $\rho$  that it has to pay. The contractee tries to maximize the payoff  $\rho$  that it receives from the contractor. Outside offers from third parties will be explicitly discussed. The contracting setting consists of two games. First, the *contracting game* involves the agents choosing a contract—or no contract, i.e. the *null deal*—before any future events have unraveled. Secondly, the *decommitting game* involves the agents deciding on whether to decommit or to carry out the obligations of the contract—after the future events have unraveled. The decommitment game is a subgame of the contracting game: the expected outcomes of the decommitting game affect the agents' preferences over contracts in the contracting game. The decommitting game will be analyzed using the Nash equilibrium and the dominant strategy concepts. The contracting game will be analyzed with respect to *individual rationality*(IR): is the contract better for an agent than the null deal?

The embodiments described herein are described in connection with FIGs. 1-6, which are described herein.

FIG. 1 shows a “sequential decommitting” (“SEQD”) game. FIG. 1 encompasses Contracting Game 20 and Decommitting Game 40. The Game Tree 10 represents two alternative protocols: i.e., two different games.

In the first, both agents have to pay decommitment penalties to each other if both decommit. In the second, neither agent has to pay if both decommit. The payoffs in the latter protocol are in parentheses when they differ from the former. The dotted lines represent information sets: the contractor does not know the contractee's outside offer and vice versa. The contractor's payoffs are usually negative because it has to pay for having the task handled.

FIG. 2 shows three graphs: left graph 110, middle graph 120, and right graph 130. FIG. 2 shows decommitment penalties a and b that satisfy both agents' IR constraints in the example SEQD game described herein. FIG. 2 shows, in graph 110, contractee's IR constraints 112, and contractor's IR constraints 114. It also illustrates, at 116, where IR constraints are satisfied, either agent might decommit.

Graph 120 shows contractor's IR constraints 122 and contractee's IR constraints 124, and the region 126 where IR constraints are satisfied, and contractee surely will not decommit.

Graph 130 shows contractor's IR constraints 132 and contractee's IR constraints 134, and the region 136 where IR constraints are satisfied, and contractor surely will not decommit.

FIG. 3 shows the "Simultaneous Decommit - Both Pay if Both Decommit" ("SIMUDBP") game. FIG. 3 shows contracting game 202 and decommitting game 204. The dashed lines represent the agents' information sets. When decommitting, the contractor does not know the contractee's outside offer and vice versa. Furthermore, the contractor has to decide on decommitting before it has observed the contractee's decommitting decision, and vice versa.

FIG. 4 illustrates Nash equilibrium decommitment thresholds of the example SIMUDBP game described herein for different values of decommitment penalties a and b. The Graphs in FIG. 4 (Graphs 302, 304 and 306) show, respectively, Nash equilibrium curves 308, 310 and 312, and the curves for truthful decommitting 314, 316 and 318.

FIG. 5 shows three different regions of contracts that are IR for both agents and allow an equilibrium of the SIMUDBP decommitting game. In the dark gray area 402, either agent might decommit; but in the light gray areas 404 and 406, only one of the agent's might.

FIG. 6 shows graphs 502, 504 and 506, comprising, respectively, Nash equilibrium curves 508, 510 and 512, and curves for truthful decommitting 514, 516 and 518.

FIGs. 1-6 are further discussed and referenced in connection with the detailed examples described herein.



$\rho$	Contract price.
$a \geq 0$	Contractor's decommitment penalty.
$b \geq 0$	Contractor's decommitment penalty.
$\tilde{a}$	Price of contractor's best (full commitment) outside offer.
$\tilde{b}$	Price of contractee's best (full commitment) outside offer.
$f(\tilde{a})$	<i>Ex ante</i> probability density function of $\tilde{a}$ .
$g(\tilde{b})$	<i>Ex ante</i> probability density function of $\tilde{b}$ .
$\rho b$	Probability that the contractee decommits.

Table 1: *Symbols used in the paper. We restrict our analysis to contracts where  $a \geq 0$  and  $b \geq 0$ , i.e. we rule out contracts that specify that the decommitting agent receives a payment from the victim of the decommitment.*

## 2. Sequential decommitting (SEQD)

In our sequential decommitting (SEQD) game, one agent has to declare decommitment before the other. We study the case where the contractee has to decommit first. The case where the contractor has to go first is analogous. Figure 1 presents the game tree. There are two alternative types of leveled commitment contracts that differ on what happens if both agents decommit. In the first, both agents have to pay the decommitment penalties to each other. In the second, neither agent has to pay.

We now analyze the decommitting game using dominance in subgames as the solution concept. Reasoning about the agents' actions starts at the leaves of the tree and proceeds backwards to the beginning of the game. In the subgame where the contractee has decommitted, the contractor's best move is not to decommit because  $-\tilde{a} - a + b \leq -\tilde{a} + b$  (because  $a \geq 0$ ). This also holds for a contract where neither agent has to pay a decommitment penalty if both decommit — because  $-\tilde{a} \leq -\tilde{a} + b$ . In the subgame where the contractee has not decommitted, the contractor's best move is to decommit if  $-\tilde{a} - a > -\rho$ .

This happens with probability  $\int_{-\infty}^{\rho-a} f(\tilde{a})d\tilde{a}$ . Put together, the contractee gets  $\tilde{b}-b$  if it decommits,  $\tilde{b}+a$  if it does not but the contractor does, and  $\rho$  if neither decommits. Thus the contractee decommits if

$$\tilde{b}-b > \int_{-\infty}^{\rho-a} f(\tilde{a})d\tilde{a}[\tilde{b}+a] + \int_{\rho-a}^{\infty} f(\tilde{a})d\tilde{a}[\rho]$$

- 5 If  $\int_{\rho-a}^{\infty} f(\tilde{a})d\tilde{a} = 0$ , this is equivalent to  $-b > a$  which is false because  $a$  and  $b$  are nonnegative. In other words, if the contractee surely decommits, the contractor does not. On the other hand, the above is equivalent to

$$\tilde{b} > \rho + \frac{b + \int_{-\infty}^{\rho-a} f(\tilde{a})d\tilde{a}[a]}{\int_{\rho-a}^{\infty} f(\tilde{a})d\tilde{a}} \text{ def } \tilde{b}^*(\rho, a, b) \quad (1)$$

when  $\int_{\rho-a}^{\infty} f(\tilde{a})d\tilde{a} > 0$ . Now the contractee's IR constraint states that the expected

- 10 payoff from the contract is no less than the expected payoff from the outside offer:

$$\int_{\tilde{b}^*(\rho, a, b)}^{\infty} g(\tilde{b})[\tilde{b}-b]d\tilde{b} + \int_{-\infty}^{\tilde{b}^*(\rho, a, b)} g(\tilde{b})\left[\int_{-\infty}^{\rho-a} f(\tilde{a})[\tilde{b}+a]d\tilde{a} + \int_{\rho-a}^{\infty} f(\tilde{a})\rho d\tilde{a}\right]d\tilde{b} \\ \geq E[\tilde{b}] = \int_{-\infty}^{\infty} g(\tilde{b})\tilde{b}d\tilde{b} \quad (2)$$

Similarly, the contractor's IR constraint states that the expected payoff from the contract is no less than that from the outside offer:

$$15 \int_{\tilde{b}^*(\rho, a, b)}^{\infty} g(\tilde{b}) \int_{-\infty}^{\infty} f(\tilde{a})[-\tilde{a}+b]d\tilde{a}d\tilde{b} + \\ \int_{-\infty}^{\tilde{b}^*(\rho, a, b)} g(\tilde{b})\left[\int_{-\infty}^{\rho-a} f(\tilde{a})[-\tilde{a}-a]d\tilde{a} + \int_{\rho-a}^{\infty} f(\tilde{a})[-\rho]d\tilde{a}\right]d\tilde{b} \\ \geq E[-\tilde{a}] = \int_{-\infty}^{\infty} f(\tilde{a})[-\tilde{a}]d\tilde{a} \quad (3)$$

- Because the contractor can want to decommit only if  $-\tilde{a}-a > -\rho$ , its decommitment penalty can be chosen so high that it will surely not decommit (assuming that  $\tilde{a}$  is bounded from below). In this case the contractee will decommit
- 20 whenever  $\rho < \tilde{b}-b$ . If  $\tilde{b}$  is bounded from above, the contractee's decommitment penalty can be chosen so high that it will surely not decommit. Thus, full commitment contracts are a subset of leveled commitment ones. This reasoning holds

for contracts where both agents have to pay the penalties if both decommit, and for contracts where neither agent has to pay a penalty if both decommit. Because full commitment contracts are a subset of leveled commitment contracts, the former can be no better in the sense of Pareto efficiency or social welfare than the latter. It follows that if there exists an IR full commitment contract, then there also exist IR leveled commitment contracts. However, leveled commitment contracts can enable deals that are impossible via full commitment contracts:

**Theorem 2.1 Enabling in a SEQD game.** *There are SEQD games (defined by  $f(\tilde{a})$  and  $g(\tilde{b})$ ) where no full commitment contract satisfies the IR constraints but a leveled commitment contract does.*

**Proof.** Let  $f(\tilde{a}) = \begin{cases} \frac{1}{100} & \text{if } 0 \leq \tilde{a} \leq 100 \\ 0 & \text{otherwise} \end{cases}$  and  $g(\tilde{b}) = \begin{cases} \frac{1}{110} & \text{if } 0 \leq \tilde{b} \leq 110 \\ 0 & \text{otherwise.} \end{cases}$  A full

commitment contract  $F$  cannot satisfy both IR constraints because that would require  $E[\tilde{b}] \leq \rho F \leq E[\tilde{a}]$  which is impossible because  $55 = E[\tilde{b}] > E[\tilde{a}] = 50$ . Choose a leveled commitment contract where  $\rho = 52.5$ ,  $a = 30$ , and  $b = 20$ . By substituting these in Equations 1, 2, and 3, it turns out that both agents' IR constraints are strictly satisfied. The substitutions are straightforward but tedious [14].

In the game of the above proof, both IR constraints are satisfied by a wide range of leveled commitment contracts—and for no full commitment contract. Which leveled commitment contracts defined by  $\rho$ ,  $a$ , and  $b$  satisfy the constraints? There are many values of  $\rho$  for which some  $a$  and  $b$  exist such that the constraints are satisfied. We analyze contracts where  $\rho = 52.5$  as an example. Now which values of  $a$  and  $b$  satisfy both IR constraints? There are three qualitatively different cases.

**Case 1. Either agent might decommit.** In the case where  $a < \rho$  there is some chance that the contractor will decommit (it may happen that  $-\tilde{a} > -\rho + a$ ). Now

$$\tilde{b}^*(\rho, a, b) = \rho + \frac{b + \int_{-\infty}^{\rho-a} f(\tilde{a}) d\tilde{a}}{\int_{\rho-a}^{\infty} f(\tilde{a}) d\tilde{a}} = \rho + \frac{b + \frac{1}{100}(\rho-a)}{\frac{1}{100}(100-(\rho-a))}. \text{ If } \tilde{b}^*(\rho, a, b) < 110 \text{ (i.e.}$$

less than maximum possible  $\tilde{b}$ ), there is some chance that the contractee will

decommit. This occurs if  $\tilde{b} > \rho + b$ . We programmed a model of the IR constraints (Equations 3 and 2) for this case. To make the algebra tractable (constant  $f(\tilde{a})$  and  $g(\tilde{b})$ ), versions of these IR constraint equations were used that assumed  $0 \leq a < \rho$ , and  $0 < \tilde{b}^* < 110$ , without loss of generality. The corresponding decommitment penalties  $a$  and  $b$  that satisfy the IR constraints are plotted in Figure 2 left. Furthermore, the boundaries of the programmed model need to be checked. The boundaries  $a = 0$ ,  $a = \rho$ , and  $\tilde{b}^* = 110$  are plotted in Figure 2 left. The constraint  $\tilde{b}^* > 0$  is always satisfied in this case and is not plotted.

**Case 2, Contractor will surely not decommit.** When  $a \geq \rho$ , the contractor will surely not decommit because its best possible outside offer is  $\tilde{a} = 0$ . Note that  $a$

can be arbitrarily high. The corresponding  $\tilde{b}^*(\rho, a, b) = \rho + \frac{b + \int_{-\infty}^{\rho-a} f(\tilde{a}) d\tilde{a} [a]}{\int_{\rho-a}^{\infty} f(\tilde{a}) d\tilde{a}} =$

$\rho + b$ , i.e. the contractee decommits truthfully. The contractor's IR constraint (Eq. 3) becomes

$$\int_{\rho+b}^{110} g(\tilde{b}) \int_0^{100} f(\tilde{a}) [-\tilde{a} + b] d\tilde{a} d\tilde{b} + \int_0^{\rho+b} g(\tilde{b}) \int_0^{100} f(\tilde{a}) [-\rho] d\tilde{a} d\tilde{b} \geq E[-\tilde{a}] \quad (4)$$

If  $\rho + b \geq 110$ , this is equivalent to  $-\rho \geq E[-\tilde{a}]$  which is false. If  $0 < \rho + b < 110$ , this is equivalent to

$$\frac{1}{110} \frac{1}{100} [(110 - (\rho + b)) \cdot \left( \frac{-(100)^2}{2} + 100b \right) + (\rho + b) \cdot (-100\rho)] \geq E[-\tilde{a}]$$

$$\Leftrightarrow \frac{1}{110} \frac{1}{100} [(57.5 - b) \cdot (-5000 + 100b) + (52.5 + b) \cdot (-5250)] \geq -50$$

$$\Leftrightarrow 2.5 \leq b \leq 52.5$$

by the quadratic equation solution formula.

Similarly the contractee's IR constraint (Eq. 2) becomes

$$\int_{\rho+b}^{110} g(\tilde{b}) \int_0^{100} f(\tilde{a}) [\tilde{b} - b] d\tilde{a} d\tilde{b} + \int_0^{\rho+b} g(\tilde{b}) \int_0^{100} f(\tilde{a}) [\rho] d\tilde{a} d\tilde{b} \geq E[\tilde{b}] \quad (5)$$

If  $\rho + b \geq 110$ , this is equivalent to  $\rho \geq E[\tilde{b}]$  which is false. If  $0 < \rho + b < 110$ , this is equivalent to

$$\int_{\rho+b}^{110} g(\tilde{b})[\tilde{b}-b] \int_0^{100} f(\tilde{a})d\tilde{a}d\tilde{b} + \int_0^{\rho+b} g(\tilde{b})[\rho] \int_0^{100} f(\tilde{a})d\tilde{a}d\tilde{b} \geq E[\tilde{b}]$$

$$\Leftrightarrow \frac{1}{110} \frac{1}{100} \left[ \left( \frac{110^2}{2} - 110b - \left( \frac{(\rho+b)^2}{2} - (\rho+b)b \right) \right) \cdot 100 + (\rho+b)\rho \cdot 100 \right] \geq 55$$

$$\Leftrightarrow b \leq \text{approximately } 34.05 \text{ or } b \geq \text{approximately } 80.95$$

by the quadratic equation solution formula. The latter violates  $\rho + b < 110$ .

- 5 Put together, in the open region  $2.5 \leq b \leq 34.05$ ,  $a \geq \rho$  (Fig. 2 right) this type of contracts are IR for both agents even though the agents decommit insincerely.

**Case 3, Contractee will surely not decommit.** If  $b$  is so high that

$\tilde{b}^*(\rho, a, b) \geq 110$ , the contractee will surely not decommit. The contractor will decommit whenever  $-\tilde{a} - a > -\rho \Leftrightarrow \tilde{a} < \rho - a$ , i.e. the decommitting threshold

- 10  $\tilde{a}^* = \rho - a$ . The contractor's IR constraint becomes

$$\int_{-\infty}^{\tilde{b}^*(\rho, a, b)} g(\tilde{b}) \left[ \int_{-\infty}^{\rho-a} f(\tilde{a})[-\tilde{a}-a]d\tilde{a} + \int_{\rho-a}^{\infty} f(\tilde{a})[-\rho]d\tilde{a} \right] d\tilde{b} \geq E[-\tilde{a}] \quad (6)$$

$$\Leftrightarrow \int_0^{110} \frac{1}{110} \left[ \int_0^{\rho-a} f(\tilde{a})[-\tilde{a}-a]d\tilde{a} + \int_{\rho-a}^{100} f(\tilde{a})[-\rho]d\tilde{a} \right] d\tilde{b} \geq -50$$

$$\Leftrightarrow \int_0^{\rho-a} 0 \int_{\rho-a}^{100} f(\tilde{a})[-\rho]d\tilde{a} \geq -50$$

If  $a \geq \rho$ , this is equivalent to  $-\rho \geq -50$  which is false. If  $0 \leq a < \rho$ , this is

- 15 equivalent to

$$\frac{1}{100} \left[ \int_0^{\rho-a} [-\tilde{a}-a]d\tilde{a} + \int_{\rho-a}^{100} [-\rho]d\tilde{a} \right] \geq -50$$

$$\Leftrightarrow \frac{1}{100} \left[ \left( \frac{-(\rho-a)^2}{2} + (\rho-a)(-a) \right) + ((100-(\rho-a)) \cdot (-\rho)) \right] \geq -50$$

$$\Leftrightarrow a \leq \text{approximately } 30.14 \text{ or } a \geq \text{approximately } 74.86$$

by the quadratic equation solution formula. The latter violates  $a < \rho$ .

- 20 Similarly, the contractee's IR constraint becomes

$$\int_{-\infty}^{\tilde{b}^*(\rho, a, b)} g(\tilde{b}) \left[ \int_{-\infty}^{\rho-a} f(\tilde{a})[\tilde{b}+a]d\tilde{a} + \int_{\rho-a}^{\infty} f(\tilde{a})[\rho]d\tilde{a} \right] d\tilde{b} \geq E[\tilde{b}] \quad (7)$$

$$\Leftrightarrow \int_0^{110} \frac{1}{110} \left[ [\tilde{b}+a] \int_0^{\rho-a} f(\tilde{a})d\tilde{a} + [\rho] \int_{\rho-a}^{100} f(\tilde{a})d\tilde{a} \right] d\tilde{b} \geq 55$$

$$\Leftrightarrow \frac{1}{110} \left[ \left( \frac{110^2}{2} + 110a \right) \int_0^{\rho-a} f(\tilde{a})d\tilde{a} + 110\rho \int_{\rho-a}^{100} f(\tilde{a})d\tilde{a} \right] \geq 55$$

$$\Leftrightarrow [55+a] \int_0^{\rho-a} f(\tilde{a}) d\tilde{a} + \rho \int_{\rho-a}^{100} f(\tilde{a}) d\tilde{a} \geq 55$$

If  $a \geq \rho$ , this is equivalent to  $\rho \geq 55$  which is false. If  $0 \leq a < \rho$ , this is equivalent to

$$[55+a](\rho-a) \frac{1}{100} + \rho[100-(\rho-a)] \frac{1}{100} \geq 55$$

$$5 \quad \Leftrightarrow \quad 2.5 \leq a \leq 47.5$$

Thus the open region  $2.5 \leq a \leq 30.14$ ,  $\tilde{b}^* \geq 110$  (Fig. 2 middle) is where this type of contracts are IR for both agents even though the agents decommit insincerely.

In addition to enabling deals that are impossible via full commitment contracts, leveled commitment contracts can increase the efficiency of deals which are possible via full commitment contracts (the reverse cannot occur because the former can emulate the latter) if there is enough *ex ante* variance in the outside offers:

**Theorem 2.2 Pareto improvement.** *If a SEQD game has at least one IR full commitment contract F and*

1.  $\tilde{b}$  is bounded from above,  $f$  is bounded, and  $\int_{-\infty}^{E[\tilde{b}]} f(\tilde{a}) d\tilde{a} > 0$ , or
- 15 2.  $\tilde{a}$  is bounded from below,  $g$  is bounded, and  $\int_{E[\tilde{a}]}^{00} g(\tilde{b}) d\tilde{b} > 0$ ,

*then that game has a leveled commitment contract that increases both agents' expected payoffs over any full commitment contract. Therefore, the leveled commitment contract is Pareto superior and IR.*

**Proof.** We prove this under condition 1. The proof under 2 is analogous. With  $F$ , the contractor's payoff is  $-\rho_F$ , and the contractee's  $\rho_F$ . We construct a leveled commitment contract where the contractee will surely not decommit because its penalty is chosen high and  $\tilde{b}$  is bounded from above. Choose  $\rho = \rho_F$  and  $a =$

$\rho_F - E[\tilde{b}] + \epsilon$ . The contractor decommits if  $-\tilde{a} - a > -\rho \Leftrightarrow \tilde{a} < \rho - a = E[\tilde{b}] - \epsilon$ .

This has nonzero probability because bounded  $f$  and  $\int_{-\infty}^{E[\tilde{b}]} f(\tilde{a}) d\tilde{a} > 0$  imply  $\exists \epsilon > 0$

25 s.t.  $\int_{-\infty}^{E[\tilde{b}]-\epsilon} f(\tilde{a}) d\tilde{a} > 0$ . The contractee's expected payoff increased: it is  $\rho_F$  if the

contractor does not decommit, and  $E[\tilde{b}] + a = \rho_F + \epsilon > \rho_F$  if the contractor does.

The contractor's expected payoff also increased:

$$\begin{aligned} -\rho_F &< \int_{-\infty}^{\rho-a} f(\tilde{a})[-\tilde{a}-a]d\tilde{a} + \int_{\rho-a}^{\infty} f(\tilde{a})[-\rho]d\tilde{a} \\ &\Leftrightarrow 0 < \int_{-\infty}^{\rho-a} f(\tilde{a})[-\tilde{a}-a+\rho_F]d\tilde{a} \end{aligned}$$

- 5 which is implied by  $\int_{-\infty}^{E[\tilde{b}]-\epsilon} f(\tilde{a})d\tilde{a} > 0$  (Because  $f$  is bounded, all of this probability mass cannot be on a single point  $\tilde{a} = \rho - a (= E[\tilde{b}] - \epsilon)$ ).

### 3 Simultaneous decommitting

- In our simultaneous decommitting games, both agents have to declare decommitment simultaneously. There are two alternative leveled commitment  
10 protocols that differ on what happens if both agents decommit, Fig. 3. In the first, both agents have to pay the decommitment penalties to each other. In the second, neither agent has to pay. The next two sections analyze them.

#### 3.1 Both pay if both decommit

- Simultaneous decommitting games where both agents have to pay the  
15 penalties if both decommit will be called SIMUDBP games, Fig. 3. Let  $\rho_b$  be the probability that the contractee decommits, which depends on  $f(\tilde{a})$ ,  $g(\tilde{b})$ ,  $\rho$ ,  $a$ , and  $b$ . The contractor decommits if

$$\rho_b \cdot (-\tilde{a} + b - a) + (1 - \rho_b)(-\tilde{a} - a) > \rho_b \cdot (-\tilde{a} + b) + (1 - \rho_b)(-\rho)$$

- If  $\rho_b = 1$ , this equates to  $a < 0$ , but we already ruled out contracts where an  
20 agent gets paid for decommitting. On the other hand, the above inequality is equivalent to

$$\tilde{a} < \rho - \frac{a}{1 - \rho_b} \text{ def } \tilde{a}^*(\rho, a, b, \tilde{b}^*) \text{ when } \rho_b < 1 \quad (8)$$

If the contractor's outside offer is below the threshold ( $\tilde{a} < \tilde{a}^*$ ), the contractor is best off by decommitting.

- 25 The contractee decommits if

$$\int_{\tilde{a}^*(\rho, a, b, \tilde{b}^*)}^{\infty} f(\tilde{a})d\tilde{a}[\tilde{b} - b] + \int_{-\infty}^{\tilde{a}^*(\rho, a, b, \tilde{b}^*)} f(\tilde{a})d\tilde{a}[\tilde{b} - b + a]$$

$$> \int_{\tilde{a}^*(\rho, a, b, \tilde{b}^*)}^{\infty} f(\tilde{a}) d\tilde{a} [\rho] + \int_{-\infty}^{\tilde{a}^*(\rho, a, b, \tilde{b}^*)} f(\tilde{a}) d\tilde{a} [\tilde{b} + a]$$

If  $\int_{\tilde{a}^*(\rho, a, b, \tilde{b}^*)}^{\infty} f(\tilde{a}) d\tilde{a} = 0$ , this equates to  $b < 0$ , but we ruled out contracts

where an agent gets paid for decommitting. However, the above inequality equates to

$$\tilde{b} > \rho + \frac{b}{\int_{\tilde{a}^*}^{\infty} f(\tilde{a}) d\tilde{a}} \stackrel{\text{def}}{=} \tilde{b}^*(\rho, a, b, \tilde{a}^*) \text{ when } \int_{\tilde{a}^*(\rho, a, b, \tilde{b}^*)}^{\infty} f(\tilde{a}) d\tilde{a} > 0 \quad (9)$$

5 If the contractee's outside offer exceeds the threshold  $\tilde{b} > \tilde{b}^*$ , the contractee is best off by decommitting. The probability that the contractee will decommit is

$$\rho_b = \int_{\tilde{b}^*(\rho, a, b, \tilde{a}^*)}^{\infty} g(\tilde{b}) d\tilde{b} \quad (10)$$

Condition 8 states the contractor's best response (defined by  $\tilde{a}^*$ ) to the contractee's strategy that is defined by  $\tilde{b}^*$ . Condition 9 states the contractee's best response  $\tilde{b}^*$  to the contractor's strategy that is defined by  $\tilde{a}^*$ . Condition 8 uses the variable  $\rho_b$  which is defined by Equation 10. So together, Equations 8, 9, and 10 define the Nash equilibria of the decommitting game.

Now the contractor's IR constraint becomes

$$\begin{aligned} & \int_{\tilde{b}^*(\rho, a, \tilde{a}^*)}^{\infty} g(\tilde{b}) \left[ \int_{-\infty}^{\tilde{a}^*(\rho, a, b, \tilde{b}^*)} f(\tilde{a}) [-\tilde{a} + b - a] d\tilde{a} + \int_{\tilde{a}^*(\rho, a, b, \tilde{b}^*)}^{\infty} f(\tilde{a}) [-\tilde{a} + b] d\tilde{a} \right] d\tilde{b} \\ 15 \quad & + \int_{-\infty}^{\tilde{b}^*(\rho, a, \tilde{a}^*)} g(\tilde{b}) \left[ \int_{-\infty}^{\tilde{a}^*(\rho, a, b, \tilde{b}^*)} f(\tilde{a}) [-\tilde{a} - a] d\tilde{a} + \int_{\tilde{a}^*(\rho, a, b, \tilde{b}^*)}^{\infty} f(\tilde{a}) [-\rho] d\tilde{a} \right] d\tilde{b} \geq E[-\tilde{a}] \end{aligned}$$

The first row corresponds to the contractee decommitting, while the second corresponds to the contractee not decommitting. The second integral in each row corresponds to the contractor decommitting, while the third integral corresponds to the contractor not decommitting. Similarly, the contractee's IR constraint becomes

$$\begin{aligned} & \int_{\tilde{b}^*(\rho, a, \tilde{a}^*)}^{\infty} g(\tilde{b}) \left[ \int_{-\infty}^{\tilde{a}^*(\rho, a, b, \tilde{b}^*)} f(\tilde{a}) [\tilde{b} - b + a] d\tilde{a} + \int_{\tilde{a}^*(\rho, a, b, \tilde{b}^*)}^{\infty} f(\tilde{a}) [\tilde{b} - b] d\tilde{a} \right] d\tilde{b} \\ 20 \quad & + \int_{-\infty}^{\tilde{b}^*(\rho, a, \tilde{a}^*)} g(\tilde{b}) \left[ \int_{-\infty}^{\tilde{a}^*(\rho, a, b, \tilde{b}^*)} f(\tilde{a}) [\tilde{b} + a] d\tilde{a} + \int_{\tilde{a}^*(\rho, a, b, \tilde{b}^*)}^{\infty} f(\tilde{a}) [\rho] d\tilde{a} \right] d\tilde{b} \geq E[\tilde{b}] \end{aligned}$$

If  $\tilde{a}$  is bounded from below, the contractor's decommitment penalty  $a$  can be chosen so high that the contractor's decommitment threshold  $\tilde{a}^*(\rho, a, b, \tilde{b}^*)$  becomes



lower than any  $\tilde{a}$ . In that case the contractor will surely not decommit. Similarly, if  $\tilde{b}$  is bounded from above, the contractee's decommitment penalty  $b$  can be chosen so high that the contractee's decommitment threshold  $\tilde{b}^*(\rho, a, b, \tilde{a}^*)$  is greater than any  $\tilde{b}$ . In that case the contractee will surely not decommit. Thus, full commitment contracts are a subset of leveled commitment ones. Therefore, the former can be no better in the sense of Pareto efficiency or social welfare than the latter.

In addition to leveled commitment contracts never being worse than full commitment ones, the following theorem shows that in SIMUDBP games they can enable a deal that is impossible via full commitment contracts.

**Theorem 3.1 Enabling in a SIMUDBP game.**

*There are SIMUDBP games (defined by  $f(\tilde{a})$  and  $g(\tilde{b})$ ) where no full commitment contract satisfies the IR constraints but a leveled commitment contract does.*

**Proof.** Let  $f(\tilde{a}) = \begin{cases} \frac{1}{100} & \text{if } 0 \leq \tilde{a} \leq 100 \\ 0 & \text{otherwise} \end{cases}$  and  $g(\tilde{b}) = \begin{cases} \frac{1}{110} & \text{if } 0 \leq \tilde{b} \leq 110 \\ 0 & \text{otherwise} \end{cases}$ .

No full commitment contract  $F$  satisfies both IR constraints because that would require  $E[\tilde{b}] \leq \rho_F \leq E[\tilde{a}]$  which is impossible because  $55 = E[\tilde{b}] > E[\tilde{a}] = 50$ . We build a leveled commitment contract with  $\rho = 52.5$  as an example. Four cases result:

**Case 1. Either agent might decommit.** If  $0 < \tilde{a}^* < 100$ , and  $0 < \tilde{b}^* < 110$ , there is a nonzero probability for each agent to decommit. The unique Nash equilibrium is plotted out for different values of  $a$  and  $b$  in Figure 4. The equilibrium decommitment thresholds  $\tilde{a}^*$  and  $\tilde{b}^*$  differ from the truthful ones. Yet there exist equilibria in the proper range of  $\tilde{a}^*$  and  $\tilde{b}^*$ .

It is not guaranteed that all of these Nash equilibria satisfy the agents' IR constraints however. We programmed a model of Equations 8, 9, and 10 and the IR constraints. To make the algebra tractable (constant  $f(\tilde{a})$  and  $g(\tilde{b})$ ), versions of these equations were used that assumed  $0 < \tilde{a}^* < 100$ , and  $0 < \tilde{b}^* < 110$ , without loss of generality. Therefore the first task was to check the boundaries of the validity of the model. The boundaries  $\tilde{a}^* = 0$  and  $\tilde{b}^* = 110$  are plotted in Figure 5. The

boundary  $\tilde{a}^* = 100$  turns out to be the line  $b = 0$ . There exists no boundary  $\tilde{b}^* = 0$  because  $\tilde{b}^*$  was always positive.

Each agent's IR constraint induces three curves (Fig. 5), two of which actually bound the IR region. The third is also a root, but at both sides of that curve, the IR constraint is satisfied. The dark gray area of Figure 5 represents the values of the decommitment penalties  $a$  and  $b$  for which the validity constraints of the programmed model and the IR constraints are satisfied. In other words, for any such  $a$  and  $b$ , there exists decommitment thresholds  $\tilde{a}^*$  and  $\tilde{b}^*$  such that these form a Nash equilibrium, and there is a nonzero probability for either agent to decommit, and each agent has higher expected payoff with the contract than without it.

**Case 2, Contractor will surely not decommit.** If  $\tilde{a}^* \leq 0$ , the contractor will surely not decommit. Now  $\tilde{b}^*(\rho, a, b, \tilde{a}^*) = \rho + \frac{b}{\int_{\tilde{a}^*}^{\infty} f(\tilde{a}) d\tilde{a}} = \rho + b$ , i.e. the contractee decommits truthfully. The contractor's IR constraint becomes the same as in case 2 of the example SEQD game (Eq. 4). This constraint was proven equivalent to  $2.5 \leq b \leq 52.5$ . The contractee's IR constraint also equates to that in the SEQD game (Eq. 5). It was proven equivalent to  $b \leq$  approximately 34.05. Thus these contracts are IR for both agents and in equilibrium in the open region  $2.5 \leq b \leq 34.05$ ,  $\tilde{a}^* \leq 0$ , Fig. 5.

**Case 3, Contractee will surely not decommit.** If  $\tilde{b}^* \geq 110$ , the contractee will surely not decommit ( $\rho_b = 0$ ). Now  $\tilde{a}^*(\rho, a, b, \tilde{b}^*) = \rho - \frac{a}{1 - \rho_b} = \rho - a$ , i.e. the contractor decommits truthfully. The contractor's IR constraint becomes the same as in case 3 of the example SEQD game (Eq. 6). This constraint was proven equivalent to  $a \leq$  approximately 30.14. The contractee's IR constraint equates to Eq. 7 of the SEQD game. It was proven equivalent to  $2.5 \leq a \leq 47.5$ . Thus the open region  $2.5 \leq a \leq 30.14$ ,  $\tilde{b}^* \geq 110$  is where these contracts are IR for both agents, and in equilibrium, Fig. 5.

**Case 4, Trivial case.** A contract where at least one agent will surely decommit, i.e.  $\tilde{a}^* \geq 100$  or  $\tilde{b}^* \leq 0$  can be IR—barely because it does not increase

either agent's payoff. For it to be IR for the decommitting agent, the decommitment penalty has to be zero: the decommitting agent gets the same payoff as without the contract. Similarly, the other agent gets the same payoff as it would get without the contract. This contract is equivalent to no contract at all: decommitment occurs and  
 5 no payment is transferred.

In addition to enabling deals that are impossible using full commitment, leveled commitment contracts can increase the efficiency of a deal even if a full commitment contract were possible (the reverse cannot occur):

**Theorem 3.2 *Pareto efficiency improvement.*** *Theorem 2.2 applies to*  
 10 *SIMUDBP games.*

**Proof.** When one agent is known not to decommit, SIMUDBP games are equivalent to SEQD games.

### 3.2 Neither pays if both decommit

Simultaneous decommitting games where a protocol is used where *neither*  
 15 *agent has to pay a decommitting penalty if both agents decommit* (SIMUDNP games, Fig. 3) can be analyzed in the same way as SIMUDBP games, but the decommitting thresholds differ.

If  $\bar{a}$  is bounded from below, and  $\tilde{b}$  from above,  $a$  can be chosen so high that the contractor will surely not decommit, and  $b$  so high that the contractee will not. So,  
 20 full commitment contracts are a subset of leveled commitment ones. Thus the former cannot enable a deal whenever the latter cannot. Also, leveled commitment can enable a deal that is impossible via full commitment:

**Theorem 3.3 *Enabling in a SIMUDNP game.*** *There exist SIMUDNP games (defined by  $f(\bar{a})$  and  $g(\tilde{b})$ ) where no full commitment contract satisfies the IR*  
 25 *constraints but a leveled commitment contract does.*

The proof is like that of Theorem 3.1 except that the formulas for decommitting differ. With the same  $f(\bar{a})$   $g(\tilde{b})$ , and  $\rho$  as in the proof of Theorem 3.1, the Nash equilibria of the SIMUDNP game are as shown in Figure 6. The decommitment thresholds  $\bar{a}^*$  and  $\tilde{b}^*$  differ from the truthful ones. They are closer  
 30 to the truthful ones than what they were with a protocol where both agents pay if both

decommit, Figure 4. The shapes of the curves using these two protocols also differ significantly.

We programmed a model to check which of the SIMUDNP equilibria allow contracts that are IR for both agents. The results are quantitatively different, but  
5 qualitatively same as in SIMUDBP games (Fig. 5).

Leveled commitment contracts can also increase the efficiency of a deal even if a full commitment contract were possible (the reverse cannot occur):

**Theorem 3.4 Pareto efficiency improvement.** *Theorem 2.2 applies to SIMUDNP games.*

10 **Proof.** When one agent is known not to decommit, SIMUDNP games are equivalent to SEQD games.

#### 4 Prescriptions for system builders

The results from the above canonical games suggest that it is worthwhile from a contract enabling and a contract Pareto improving perspective to incorporate the  
15 decommitment mechanism into automated contracting protocols. The decommitment penalties are best chosen by the agents dynamically at contract time as opposed to statically in the protocol. This allows the tuning of the penalties not only to specific negotiation situations and environmental uncertainties, but also to specific belief structures of the agents. An extended paper analyzes the impact of agents' biased  
20 beliefs on the benefits of contracts, and the distribution of these gains.

In the presented instance of the simultaneous decommitting game, the Nash equilibrium decommitting strategies were usually closer to truthful ones when a protocol was used where neither pays if both decommit than when a protocol was used where both pay if both decommit. Also, as an agent's opponent's decommitment  
25 penalty approaches zero, the agent becomes truthful in the former protocol, but starts to increasingly bias its decommitment decisions in the latter. This suggests using the former protocol in practical systems. It also minimizes the number of payment transfers because it does not require any such transfer if both decommit.

In a web of multiple mutual contracts among several agents, classical full  
30 commitment contracts induce one negotiation focus consisting of the obligations of the contracts. Under the protocol proposed in this paper, there are multiple such foci,

and any agent involved in a contract can swap from one such focus to another by decommitting from a contract. Such a swap may make it beneficial for another agent to decommit from another contract, and so on. To avoid loops of decommitting and recommitting in practice, recommitting can be disabled. This can be implemented by  
5 a protocol that specifies that if a contract offer is accepted and later either agent decommits, the original offer becomes void—as opposed to staying valid according to its original deadline which may not have been reached at decommitment time.

Even if two agents cannot explicitly recommit to a contract, it is hard to specify and monitor in a protocol that they will not make another contract with an  
10 identical content. This gives rise to the possibility of the equivalent of useless decommit-recommit loops. Such loops can be avoided by a mechanism where the decommitment penalties increase with real-time or with the number of domain events or negotiation events. This allows a low commitment negotiation focus to be moved in the joint search space while still making the contracts meaningful by some level of  
15 commitment. The increasing level of commitment causes the agents to not backtrack deeply in the negotiations, which can also save computation.

The initially low commitment to contracts can also be used as a mechanism to facilitate linking of deals. Often, there is no contract over a single item that is beneficial, but a combination of contracts among two agents would be. Even if  
20 explicit clustering of issues into contracts is not used, an agent can agree to an unbeneficial contract in anticipation of synergic future contracts from the other agent that will make the first contract beneficial. If no such contracts appear, the agent can decommit. Similarly, low commitment contracts can be used to facilitate deals among more than two agents. Even without explicit multiagent contract protocols,  
25 multiagent contracts can be implemented by one agent agreeing to an unbeneficial contract in anticipation of synergic future contracts from third parties that will make the first contract beneficial. If no such contracts appear, the agent can decommit.

In many practical automated contracting settings limited computation resources bound the agents' capability to solve combinatorial problems. The value of  
30 a contract may only be probabilistically known to an agent at contract time. The leveled commitment contracting protocol allows the agent to continue deliberation

- regarding the value of the contract after the contract is made. If the value turns out to be lower than expected, the agent can decommit. However, decommitment penalties which increase quickly in time may be appropriate with computationally limited agents so that the agents do not need to consider the combinatorial number of possible
- 5 future worlds where alternative combinations of decommitments have occurred.

Certain embodiments of the present invention are described in detail above. It will be understood by those skilled in the art that the present invention is defined solely by the claims, and that other embodiments and many modifications to the above described embodiments are within the scope of the invention, as defined by the

5    claims.

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## CLAIMS

**1**

**2 What is claimed is:**

3           1.       A method for entering into an efficient, automated contract, comprising

**4 the steps of:**

5           a first agent committing to a first obligation;

6 a second agent committing to a second obligation in exchange for the

**7 first obligation; and**

8 determining, ex ante, a decommitment penalty applicable to at least

9 one of said obligations.



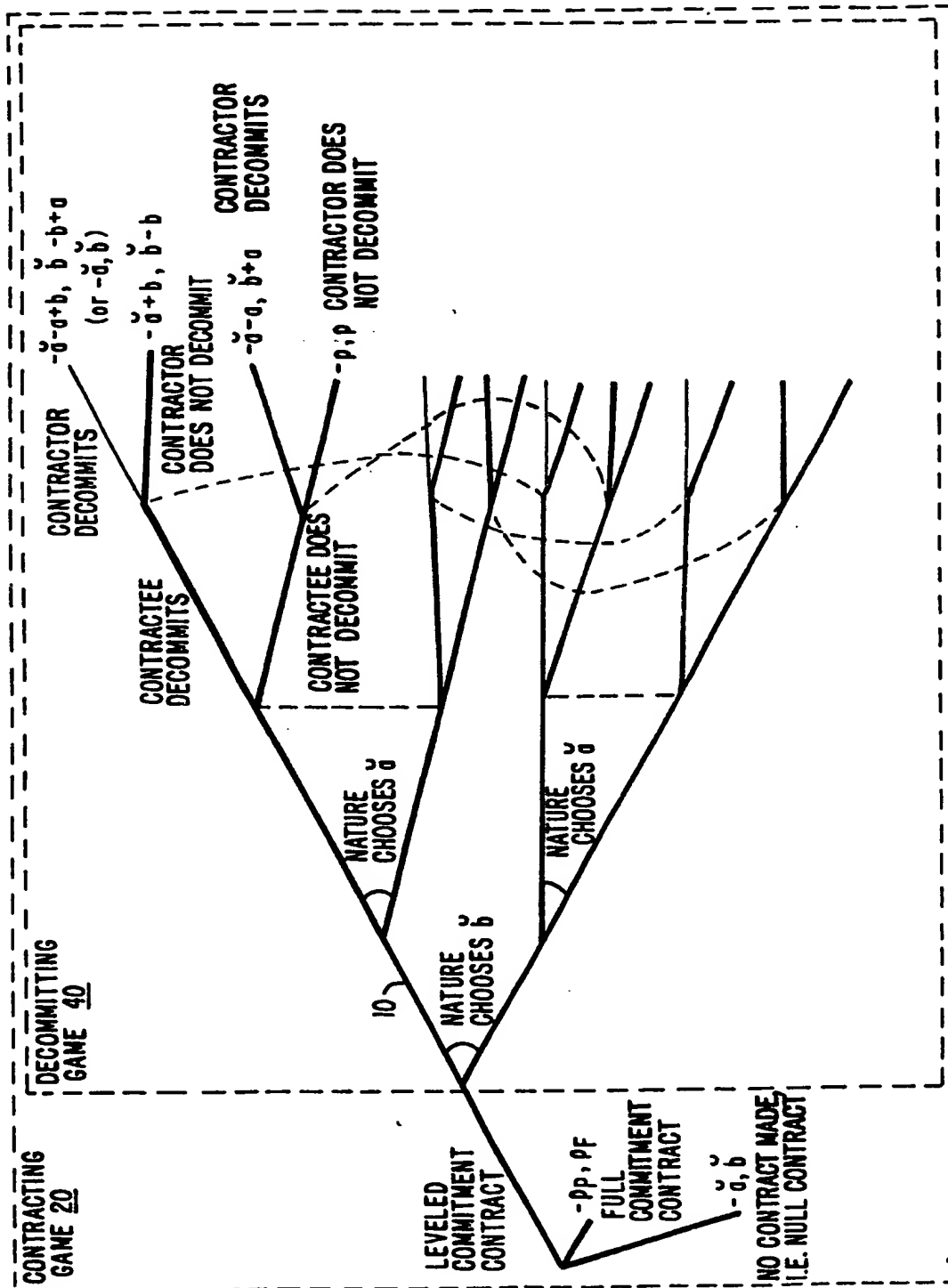


FIG. 1.

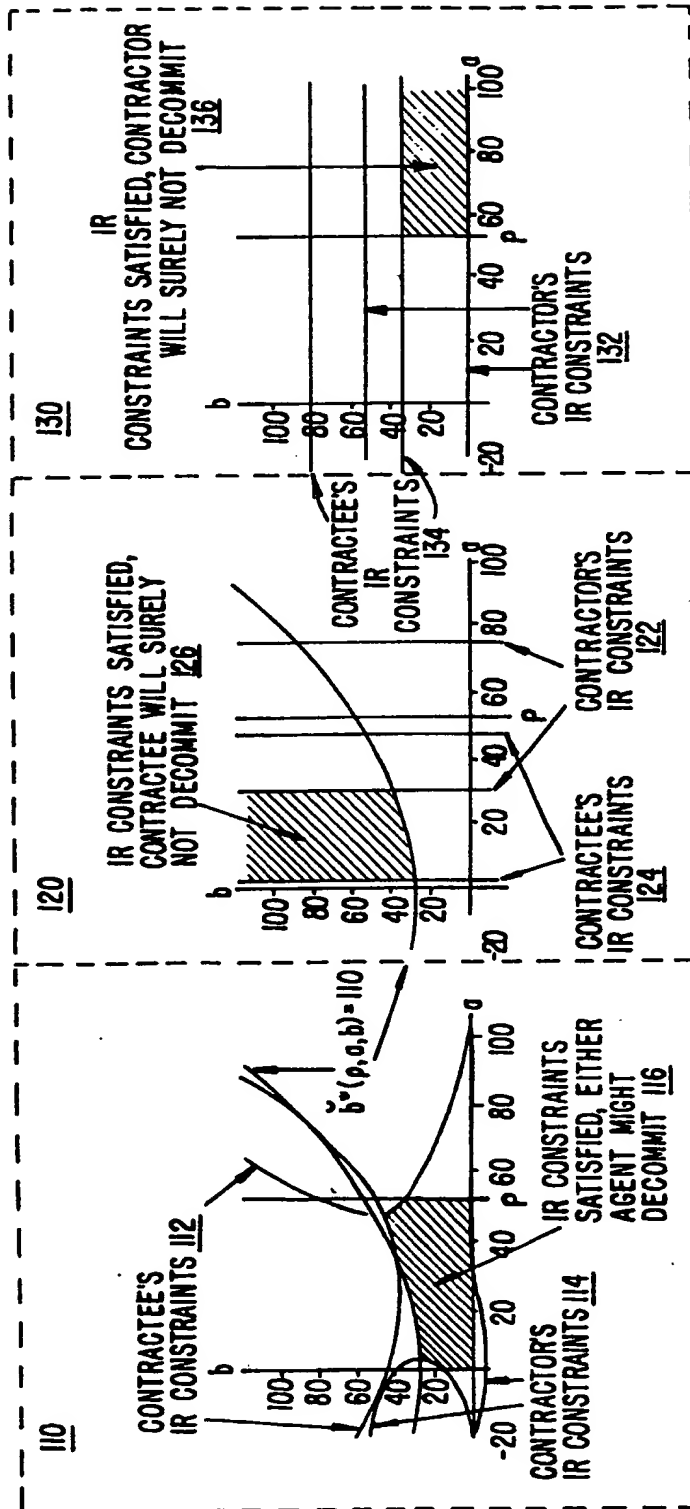
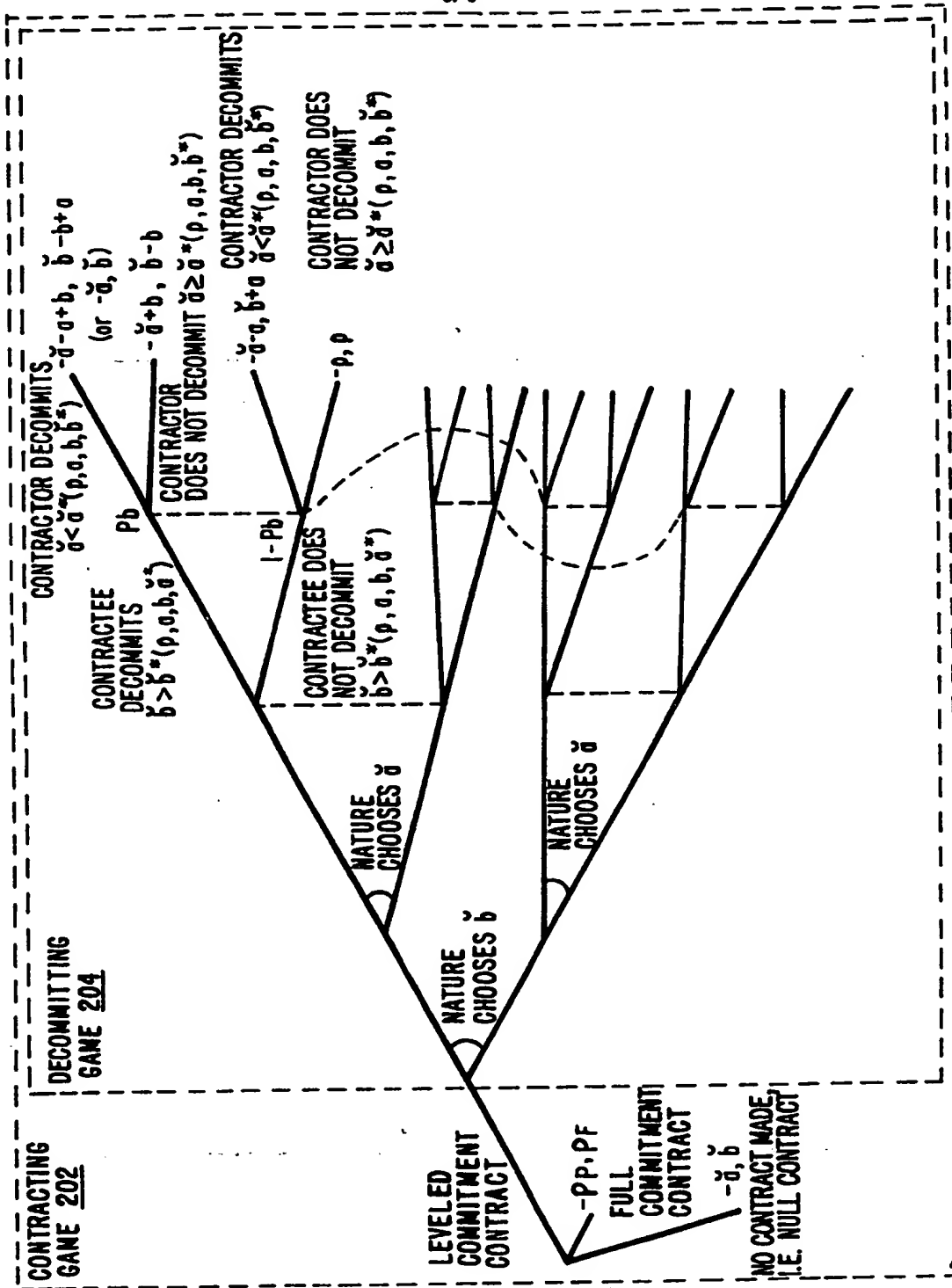


FIG. 2.



**FIG. 3.**

4/6

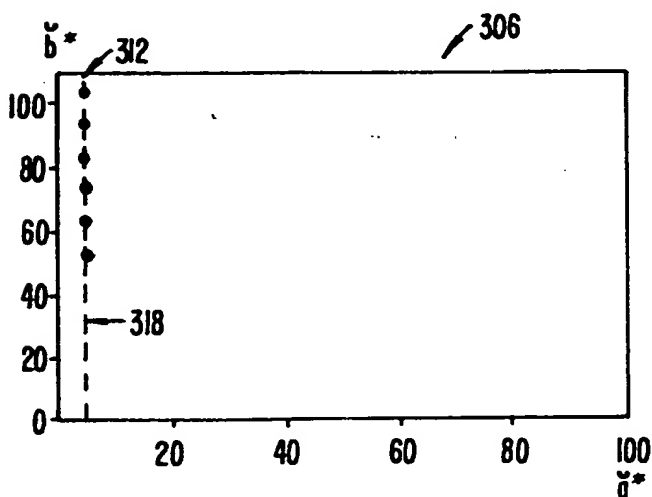
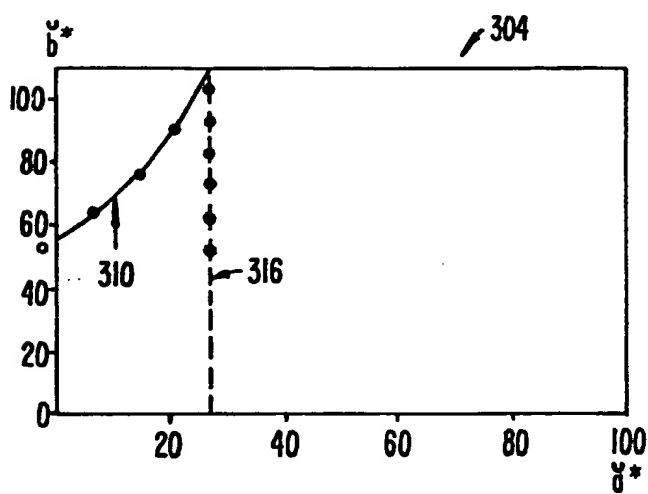
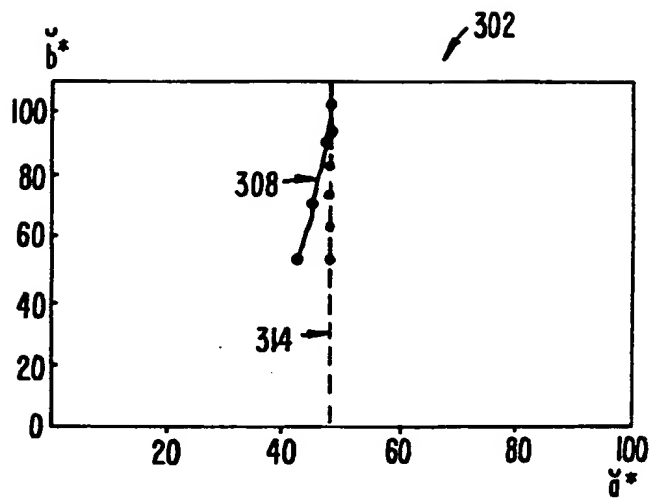


FIG. 4.

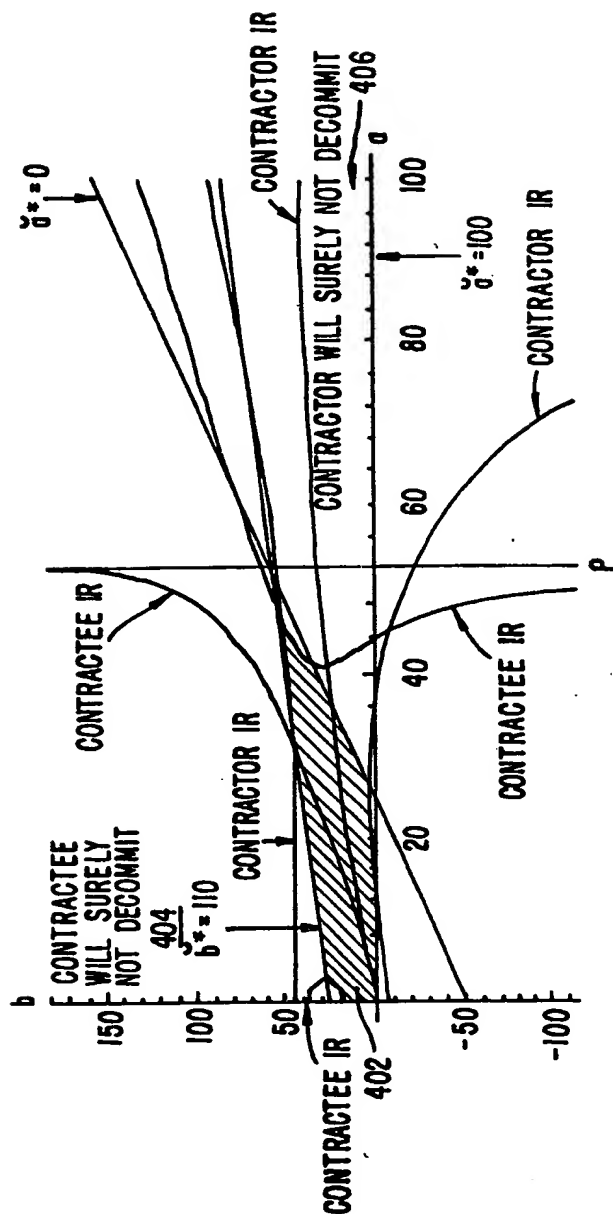
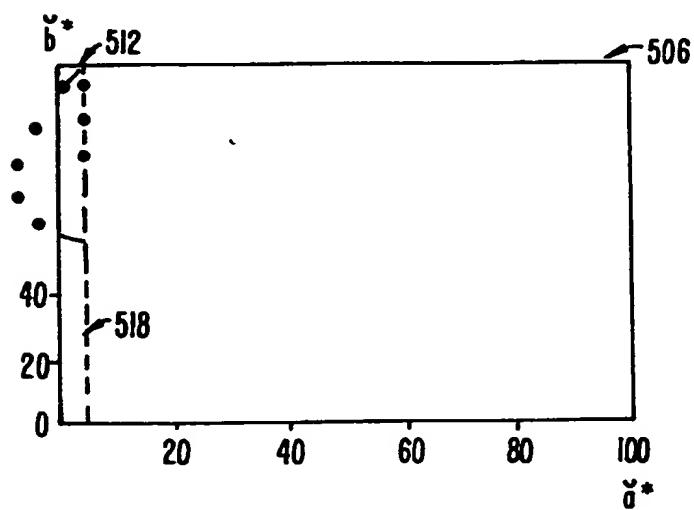
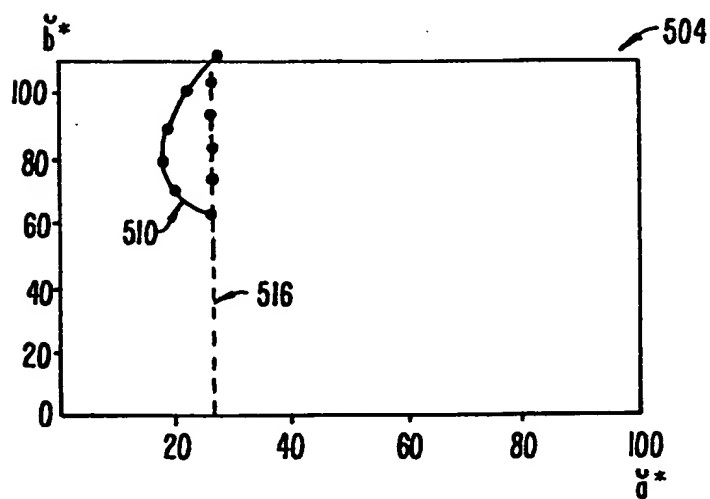
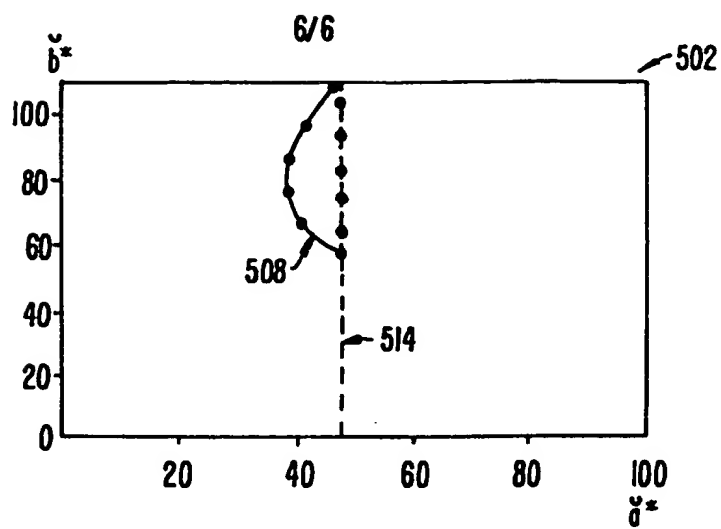


FIG. 5.

**FIG. 6.**

# INTERNATIONAL SEARCH REPORT

Int'l Application No

PCT/US 98/15729

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 G06F17/60 G06F17/10 G06F9/44

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SANDHOLM T W ET AL: "Advantages of a leveled commitment contracting protocol" PROCEEDINGS OF THE THIRTEENTH NATIONAL CONFERENCE ON ARTIFICIAL INTELLIGENCE AND THE EIGHTH INNOVATIVE APPLICATIONS OF ARTIFICIAL INTELLIGENCE CONFERENCE, PROCEEDINGS OF NATIONAL CONFERENCE ON ARTIFICIAL INTELLIGENCE, PORTLAND, OR, USA, 4-8 AUG. 1996, pages 126-133 vol.1, XP002086844 ISBN 0-262-51091-X, 1996, Cambridge, MA, USA, MIT Press, USA see abstract  -/-	1



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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Date of the actual completion of the international search

4 December 1998

Date of mailing of the international search report

21/12/1998

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# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/15729

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SANDHOLM T ET AL: "Issues in automated negotiation and electronic commerce: Extending the contract net framework" ICMAS-95 PROCEEDINGS. FIRST INTERNATIONAL CONFERENCE ON MULTI-AGENT SYSTEMS, PROCEEDINGS OF FIRST INTERNATIONAL CONFERENCE ON MULTIAGENT SYSTEMS, SAN FRANCISCO, CA, USA, 12-14 JUNE 1995, pages 328-335, XP002086845 ISBN 0-262-62102-9, 1995, Menlo Park, CA, USA, AAAI Press, USA see page 332, column 334	1
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